Waterborne microorganisms and disease: The need for disinfection.

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Bacteria

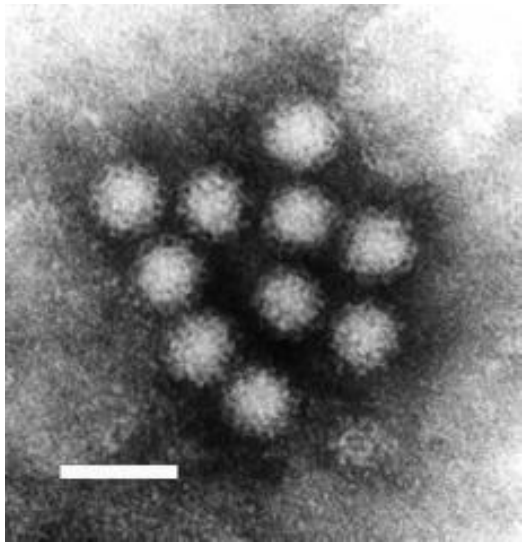
(e.g. *E. coli*, *Salmonella*)

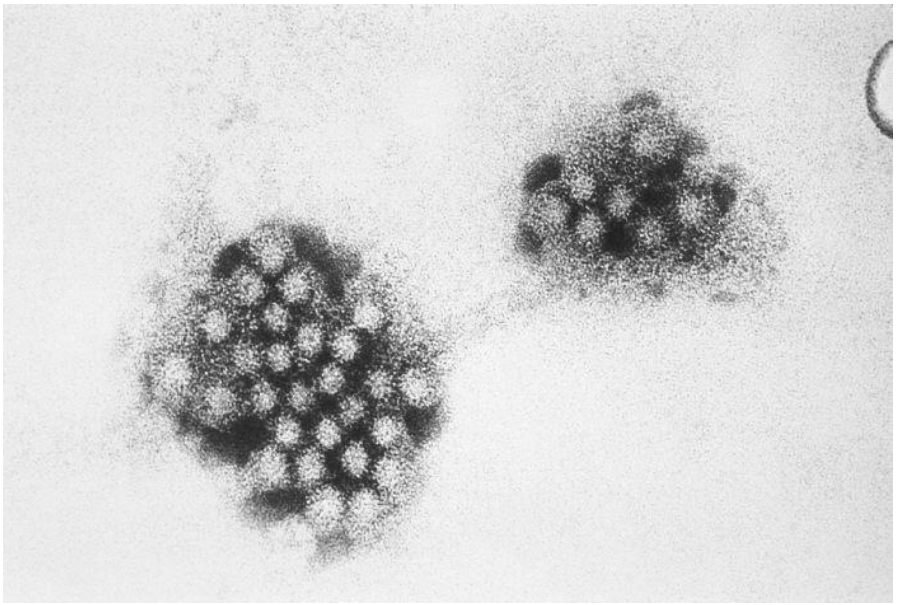
Size: 1-10 µm

Viruses

(e.g. noroviruses)

Size 10-300 nm

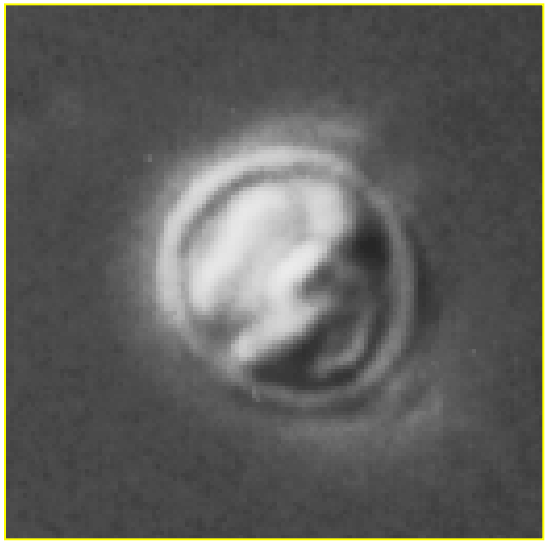




Protozoa

(e.g. *Cryptosporidium*, *Giardia*, microsporidia)

Size: 1-12 µm



Waterborne diseases

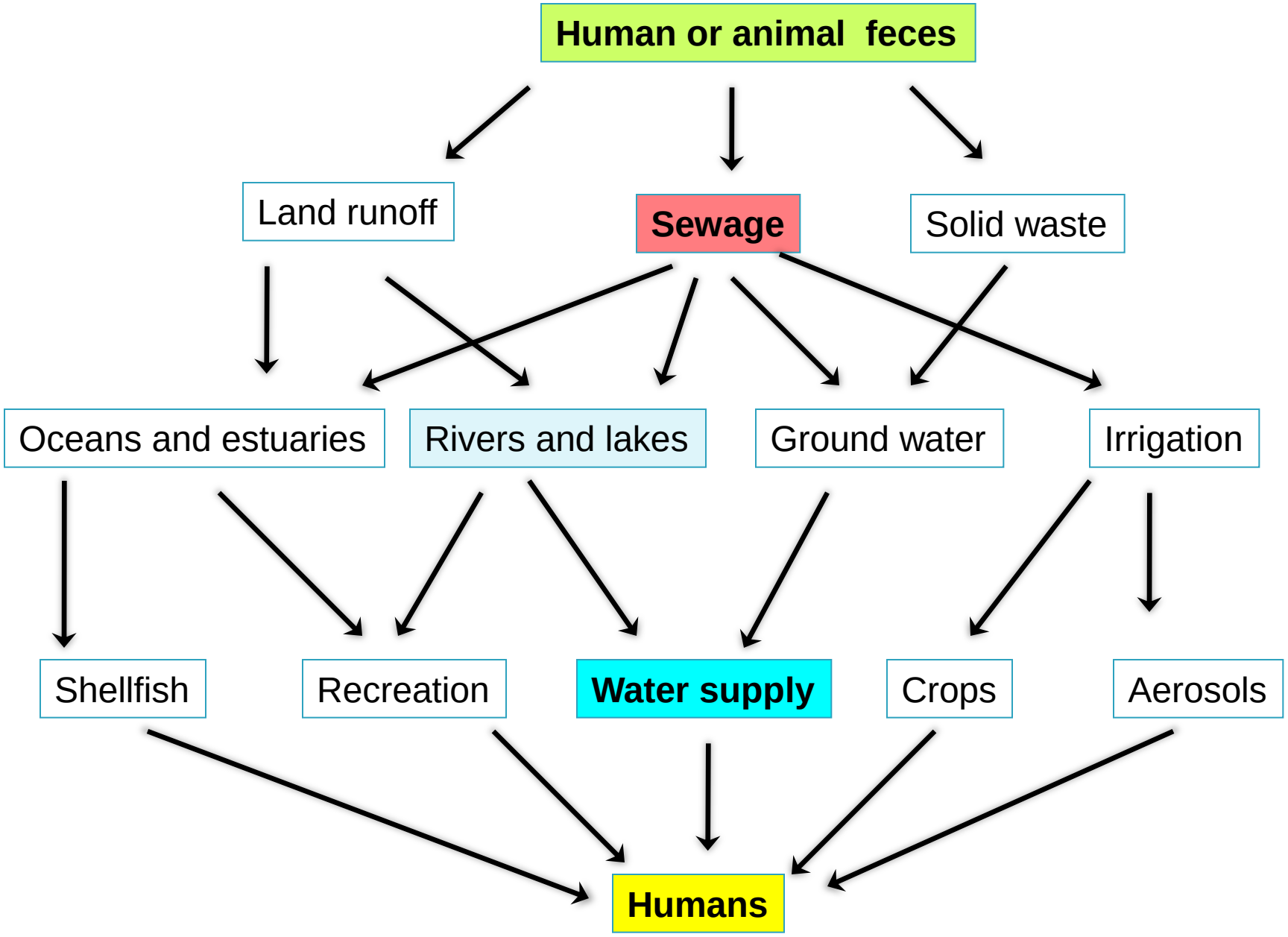
- **Infection**: the invasion of a host by an infectious microorganism.
- **Pathogen**: a disease-causing microorganism.

Who gets sick? (host susceptibility factors)

- Immune response affected:
  - Age
  - Genes
  - Nutrition
  - Hygiene
  - Stress
  - Diabetes
  - Viral infection (e.g. HIV/AIDS)
  - Drug therapies
- Immunodeficient/immunocompromised individuals
  - Elderly, infants, AIDS

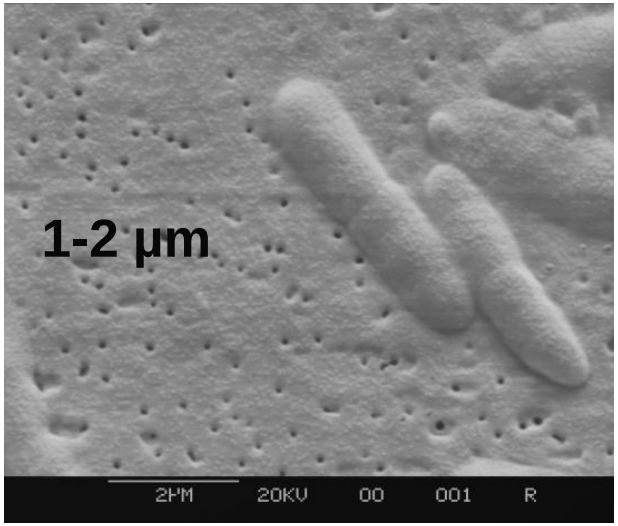
Some pathogens are often found in water

- 10^{12} bacteria /g feces (plus viruses/protozoa)
- Contamination from:
  - Fecal matter from sewage discharges
  - Leaking septic tanks
  - Runoff from animal feedlots into streams
  - Fecal matter from birds and other wildlife/domestic animals
  - Leaking/cracked water pipes
  - Drinking water treatment deficiencies

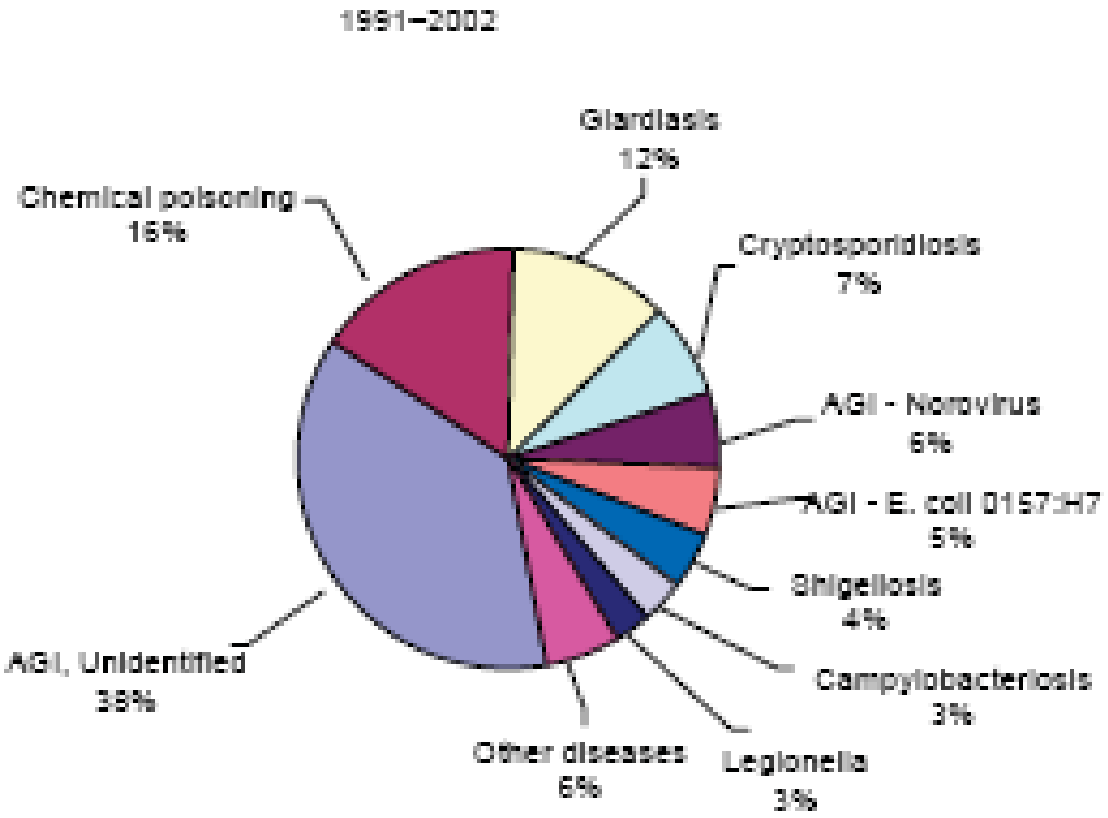

Human or animal feces
Land runoff
Sewage
Solid waste
Oceans and estuaries
Rivers and lakes
Ground water
Irrigation
Shellfish
Recreation
Water supply
Crops
Aerosols
Humans

Fecal coliform indicators

- **Bacteria associated with human or animal wastes.**
- **Hundreds of types**
- **Intestinal tracts.**
- **Their presence in water (or in food) is a strong indication of recent sewage or animal waste contamination.**



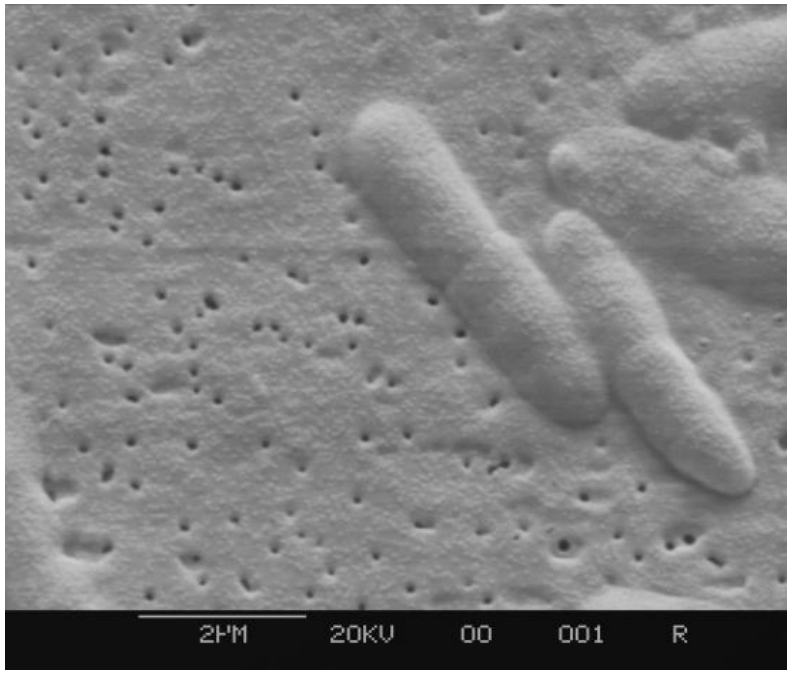
Etiologies of waterborne outbreaks in the U.S. (1991-2002).
(From Craun *et al.* 2006. J. Water and Health)



E. coli O157:H7 (bacterium)

Hemorrhagic syndrome & hemolytic uremic syndrome

- **U.S.: app. 73,000 cases/year (50-100 deaths)**
- **Foodborne & waterborne**
  - **"Hamburger disease" in 1993**
  - **Spinach in 2006**
- **From cattle feces**
- **In humans, a toxin is made**
- **Affects GI tract & kidneys**
  - **Bloody diarrhea**
  - **Anemia, death possible**
  - **Children/elderly most at risk**

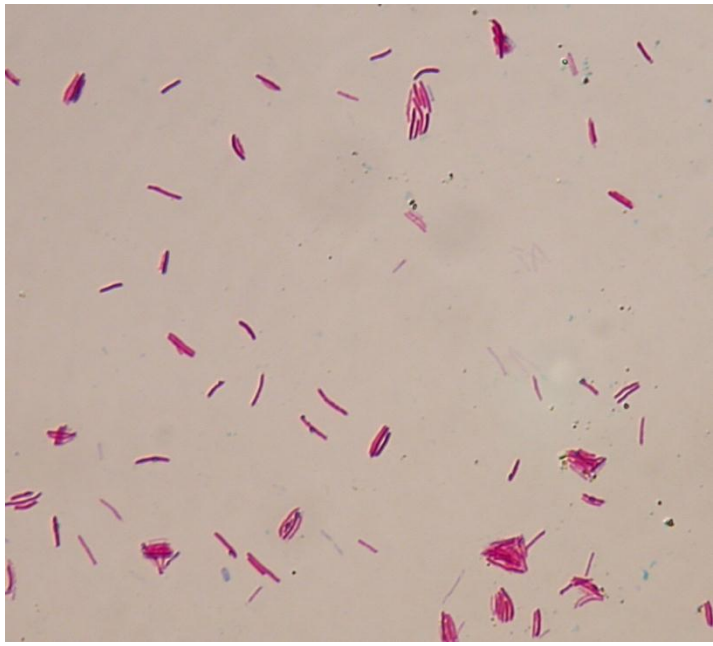


Shigella

- Shigellosis
- Gram negative rod-shaped bacterium
- Invasive pathogen
- Bacterial dysentery - bloody stools
- ID_{50} = 10 (app.)
- Persists less than fecal coliforms in the environment

Atypical mycobacteria - *Mycobacterium avium* complex (MAC)

- Nontuberculosis mycobacteria
- Acid-fast bacteria = environmentally resistant
  - Resistant to usual chlorine disinfectant CT values
- Generalized infection
- Third cause of death in AIDS patients
- Isolated from:
  - 40% of human stools
  - pigs, birds
- Plant effluents: few cells per L
- Regrowth in biofilm



Viral pathogens

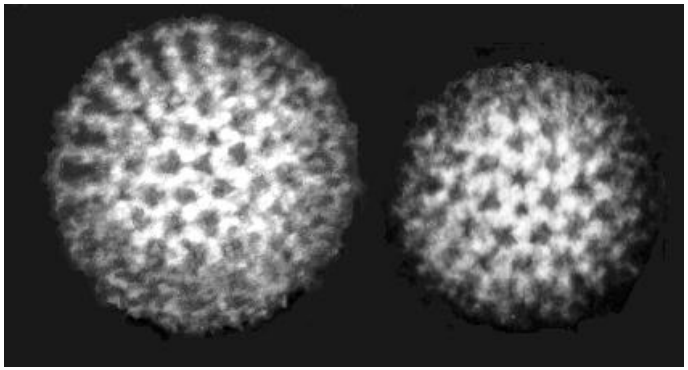
- 140 types of enteric viruses

  ingested → reproduce in GI tract → shed in feces

- Present in small numbers in water

- Difficult to detect

- E.g. Rotavirus, Noroviruses (Norwalk)



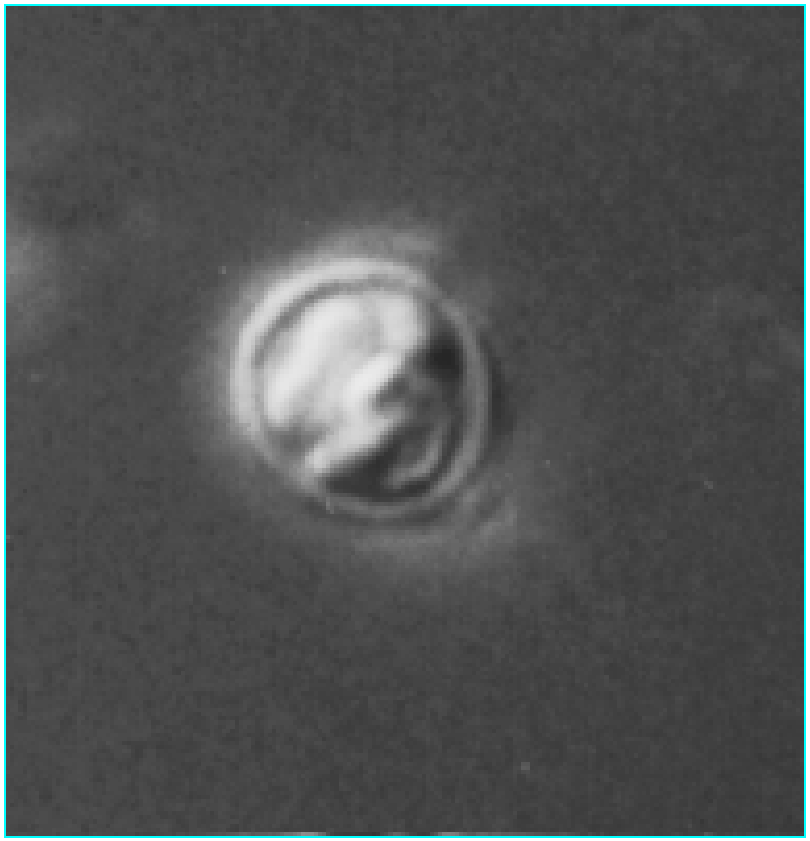
Giardia lamblia

- Flagellated protozoan
- Cysts are relatively chlorine-resistant
- Ubiquitous in water
- Reservoirs are humans, wild and domestic animals

Giardiasis

- Diarrhea, abdominal pains, cramps, fatigue, etc.
- Several weeks
- 100 million cases per year (worldwide)
- Drugs $\Rightarrow$ metronidazole
- ID_{50} = **25-100** in healthy humans

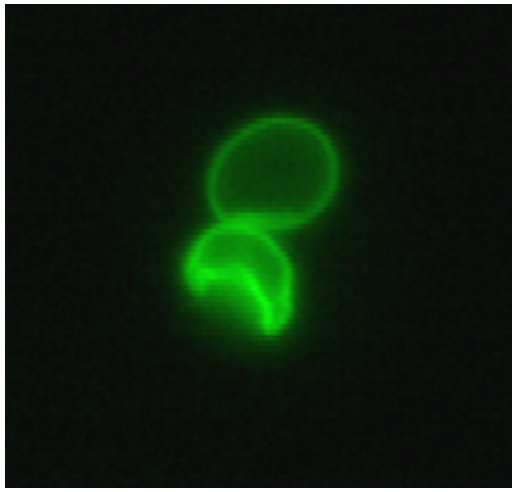
Cryptosporidium parvum



- Protozoan Parasite
- 4-6 µm diameter
- Oocysts and 4 Sporozoites
- Human Pathogen
- Gastroenteritis
- AIDS
- Water transmission
- Oocysts resistant to conventional chemical disinfectants
  - UV works well

Cryptosporidiosis

- Incubation: 2 to 10 days
- Symptoms
  - Diarrhea, vomiting, fever, cramping,
  - Last 2 weeks
- Oocysts excreted for up to 60 days
- No specific drug
- Potentially fatal to immunocompromised individuals
  - they shed 10^{9}-10^{12} oocysts/day
- Healthy Volunteers Study (ID_{50}=132)



Water route
Foodborne
Fecal-oral

Sprozoites:
-Intestines

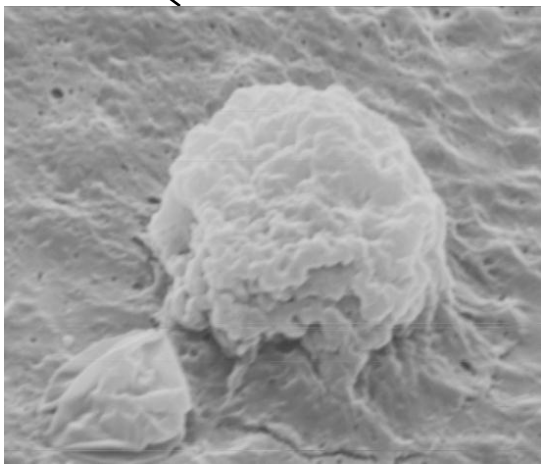
-Infection & toxin

-Intestines

-Feeding stage

Sexual multiplication

Oocysts:
- **Environmental stage**
- **Shed in feces**
- **Resistant**



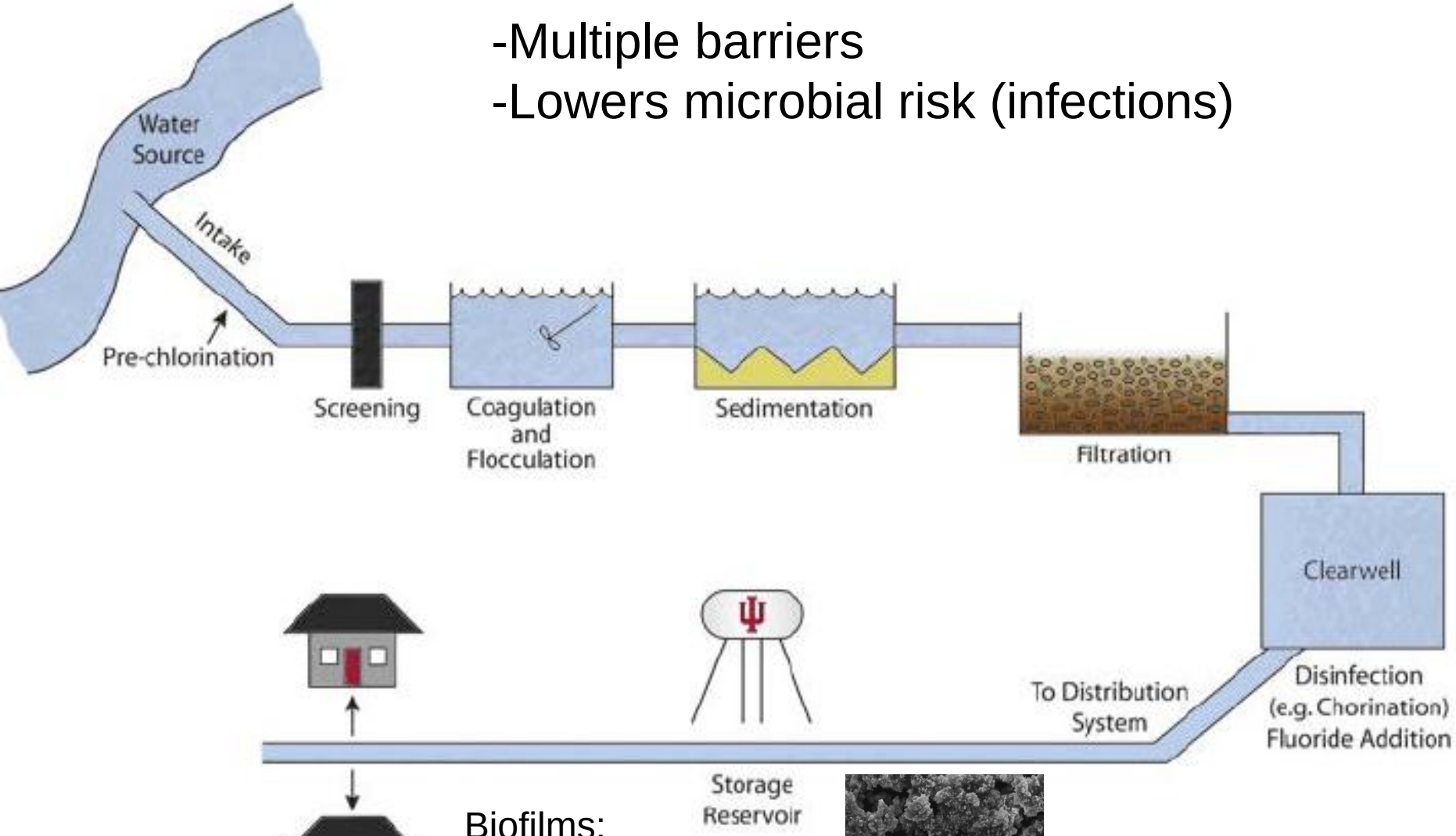
Various life cycle stages in intestines

Cryptosporidium parvum
- Waterborne Outbreaks

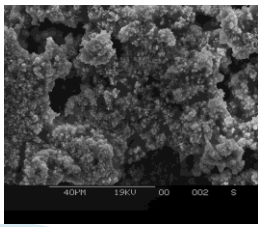
- Braun Station, TX (1984), 2000 cases
- Ayrshire, UK (1986), 62 cases
- Carrolton, GA (1987), 13000 cases
- Jackson County, OR (1992), 15000 cases
- Milwaukee, WI (1993), 403,000 cases
- Kitchener, ON, Can. (1993), 1000 cases
- Las Vegas (1994) 78 cases
- British Columbia (1996), 15000
- Sydney, Australia (1998)
- North Battleford, Saskatchewan (2001), 1907 cases
- North Wales, UK (2005), 200 cases
- Galway, Ireland (2007), 242 cases

Conventional Drinking Water Treatment

-Multiple barriers
-Lowers microbial risk (infections)



Biofilms:
-Pathogen regrowth
-Taste and odor



New(er) technologies

- Alternative disinfectants
  - Ozone
  - Chlorine dioxide
- Ultraviolet light
- Membrane filtration

Principles of Drinking Water Disinfection

- **Disinfection:** the inactivation of disease-causing microorganisms by the addition of a chemical into water or by the application of UV light.
- **First used:** chlorine about 100 years ago
- **Inactivation:** loss of infectivity in humans
- **Sterilization:** the destruction (death) of all living organisms in a material

What is “disinfected water”?

- **Disinfected water is not “sterile”**
  - HPC bacteria, etc.
- **Disinfected water:**
  - A desired level of microorganism inactivation has been achieved in order to minimize the health risk and reduce it to an *acceptable* level.
- **Acceptable risk: 1 in 10,000 rule**
  - Treatment should ensure that populations are not subject to risk greater than one infection per 10,000 people per year.

Factors influencing disinfection

- Type of disinfectant
  - Monochloramine < chlorine < chlorine dioxide < ozone
  - Ultraviolet irradiation (UV)
- Type of microorganisms

Vegetative bacteria < enteric viruses < spore-forming bacteria/protozoan cysts

- Temperature
- pH
  - E.g. Cl_2: Disinfection efficiency increases with decreasing pH
- Surfaces, biofilms, and “clumping”

Factors influencing disinfection

- Disinfectant concentration (C) and contact time (t)

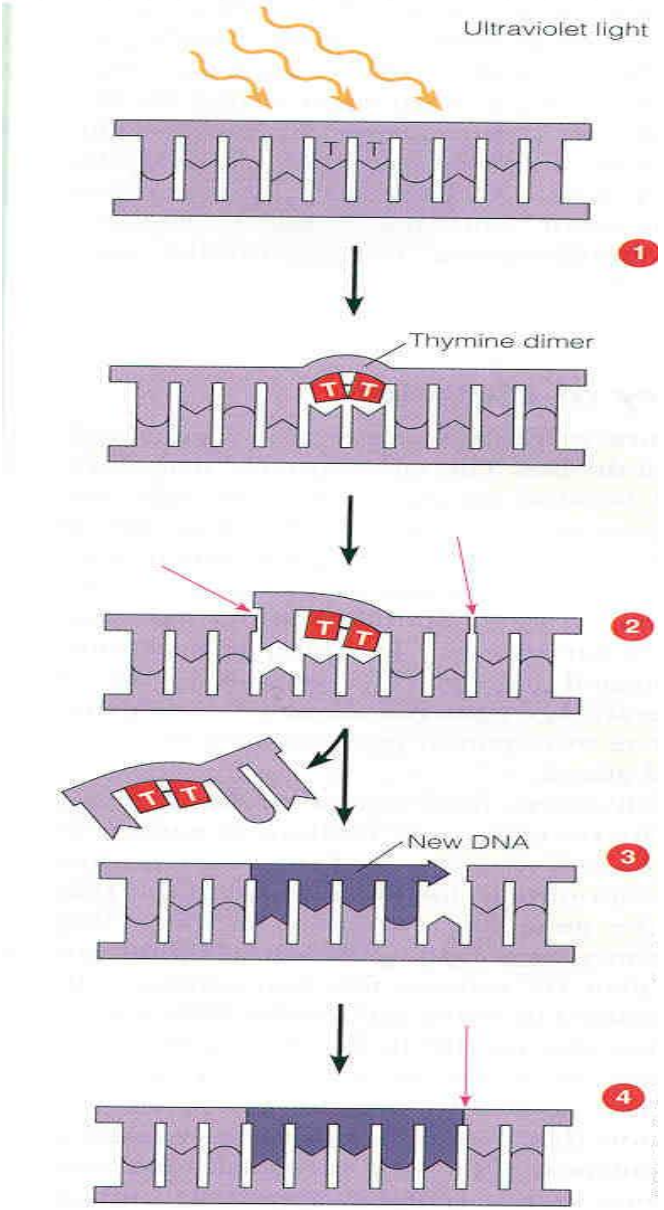
$$K = C^n t$$

- kill is proportional to C x t
- *Ct* also accounts for temperature and pH

An example: *Ct* values for the inactivation of *Giardia* cysts in water at 10°C with pH 6.0-9.0 (source: U.S. EPA)

	Ct values (mg.min/L)		
Disinfectant	**0.5-log inact.**	**1-log inact. (90% kill)**	**2-log inact. (99% kill)**
Chloramine	**310**	**615**	**1,230**
Chlorine	**17**	**35**	**69**
Chlorine dioxide	**4**	**7.7**	**15**
Ozone	**0.23**	**0.48**	**0.95**

Mechanisms of action of UV radiation (200-300 nm)



Cell's DNA

= MUTATION

or

DEATH

DNA-REPAIR MECHANISMS

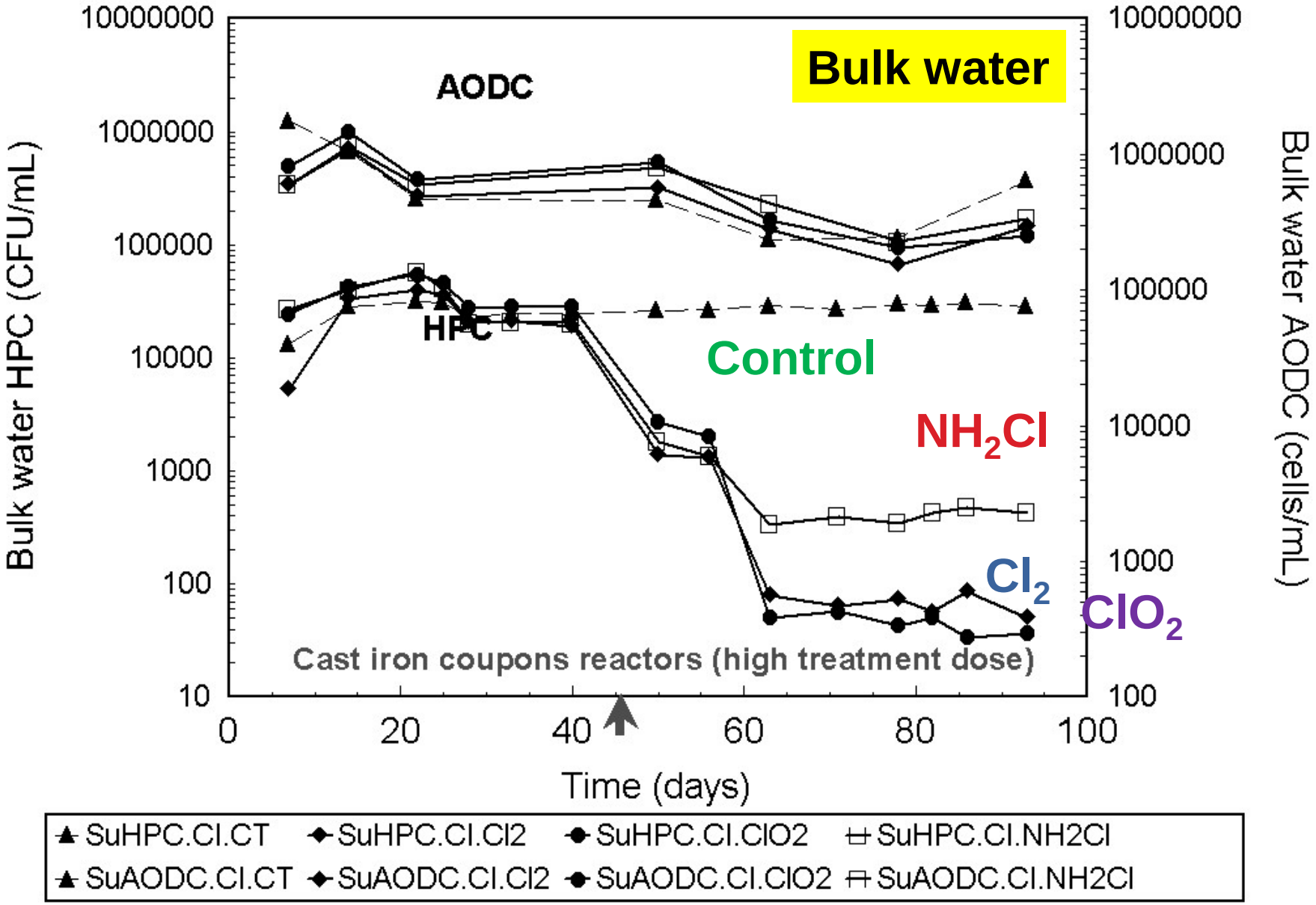
SURVIVAL

UV DOSE REQUIREMENTS FOR CRYPTOSPORIDIUM, GIARDIA, AND VIRUS INACTIVATION CREDIT (SOURCE: EPA'S LT2)

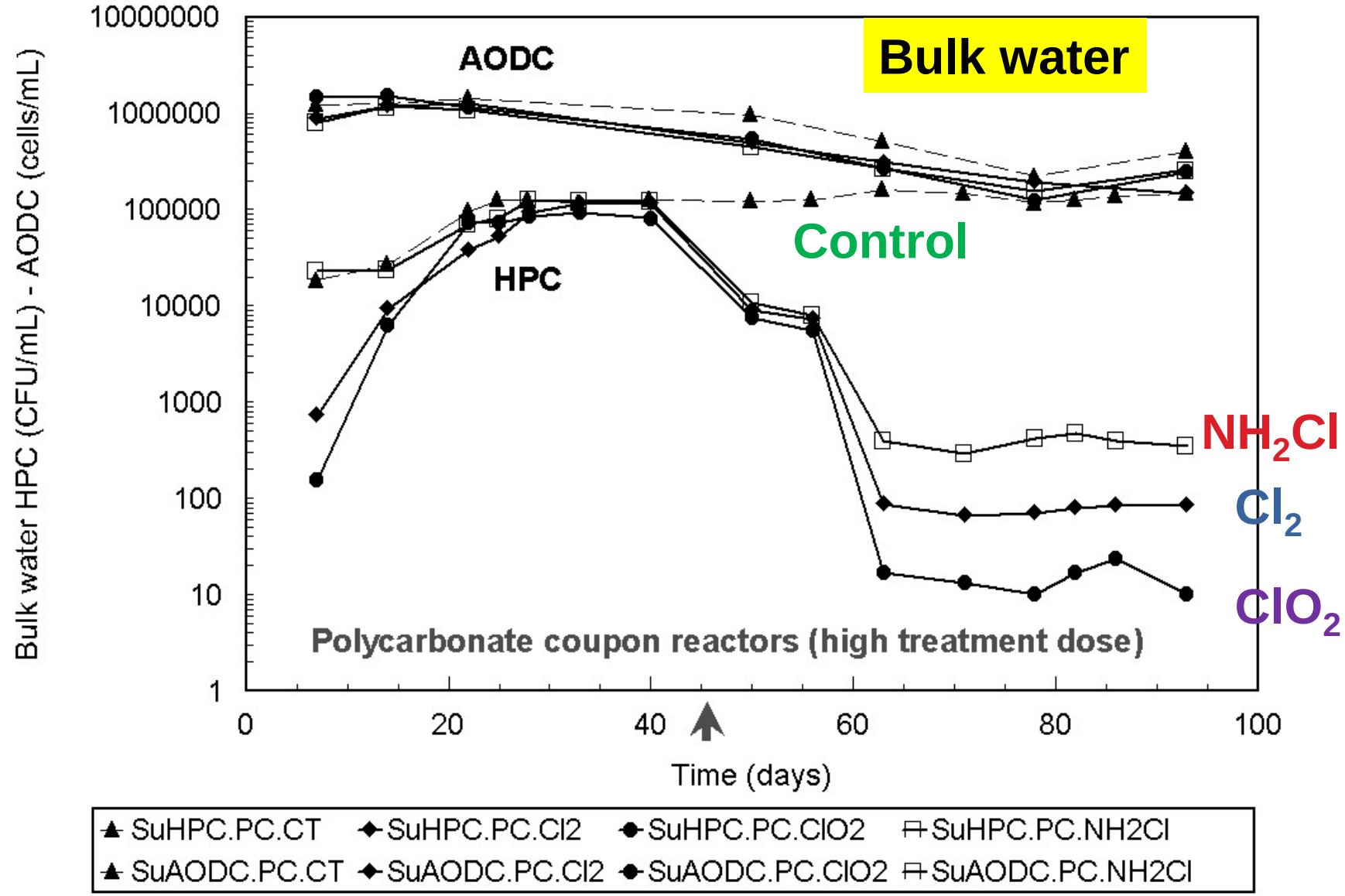
Log credit	*Cryptosporidium* UV dose (mJ/cm^2)	*Giardia* UV dose (mJ/cm^2)	Virus UV dose (mJ/cm^2) e.g. Adenoviruses
1.0 (90% kill)	3.9	3.0	79
2.0 (99% kill)	5.8	5.2	100
3.0 (99.9% kill)	12	11	143
4.0 (99.99% kill)	22	22	186

Comparison of Secondary Disinfectants in Distribution Systems

- Free Chlorine:
  - Often increased chlorine dosages are required to suppress biofilm bacteria
  - Concern: Elevated DBP concentrations
- Chlorine dioxide:
  - More effective at controlling *Cryptosporidium*
  - Very positive results in terms of DBPs and water quality after switching from Cl_2 to ClO_2
- Chloramines:
  - Chloramines effective for cast-iron pipes
  - Main concern with chloramines is nitrification; excess ammonia serves as a nutrient source



Effect of high disinfectant concentrations on suspended HPCs (SuHPC) and suspended AODC (SuAODC) counts for cast iron (CI) DS reactors. (CT=control AR; Cl2 = free chlorine; ClO2 = chlorine dioxide; NH2Cl = chloramines). Arrow indicates when disinfectant was applied. (Gagnon et al. 2005)



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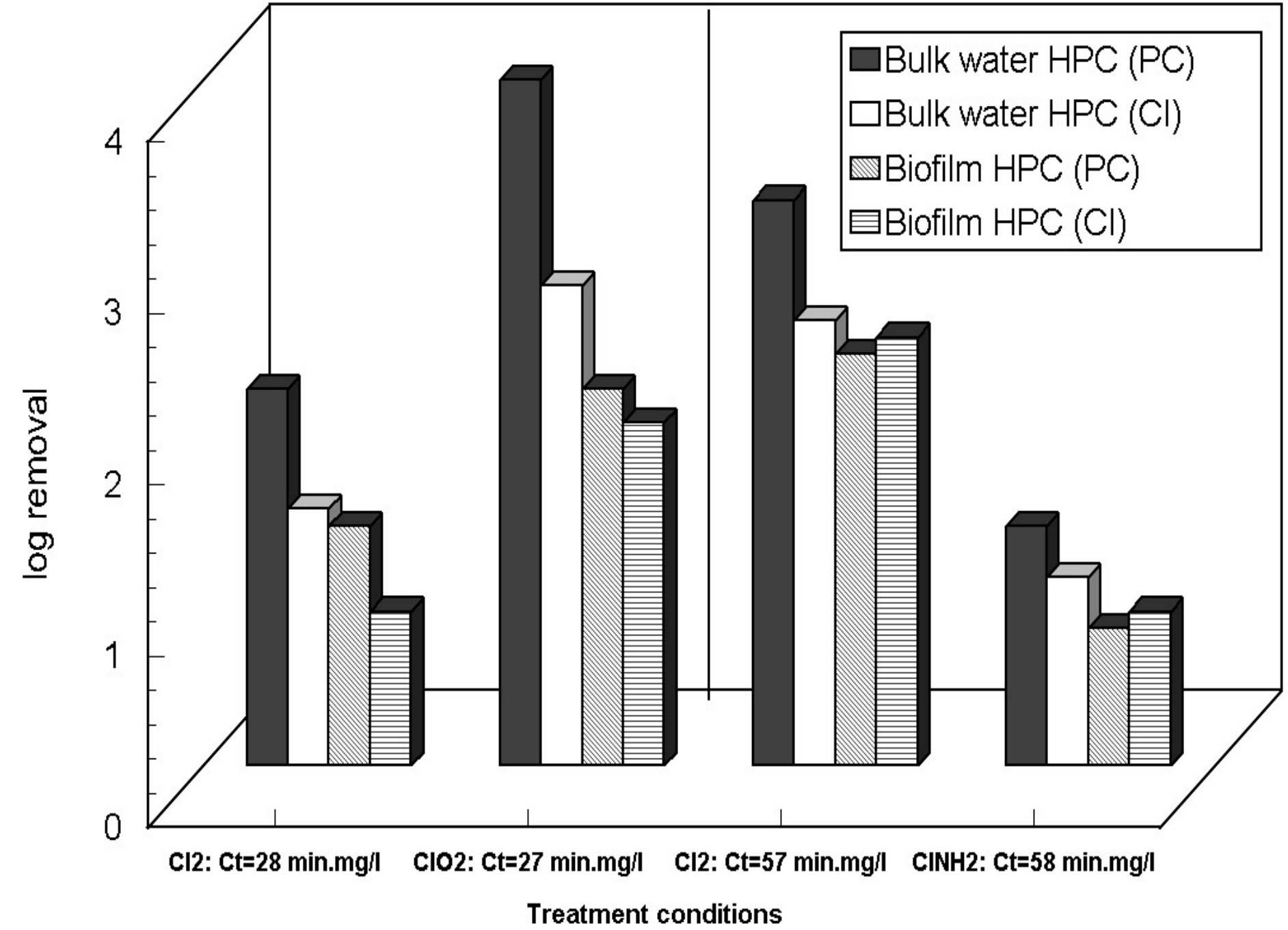
Bulk water HPC (PC)
Bulk water HPC (Cl)
Biofilm HPC (PC)
Biofilm HPC (Cl)
log removal
0
1
2
3
4
Cl2: Ct=28 min.mg/l
ClO2: Ct=27 min.mg/l
Cl2: Ct=57 min.mg/l
ClNH2: Ct=58 min.mg/l
Treatment conditions

Waterborne outbreaks - 2 cases

- Cryptosporidiosis in Milwaukee
- *E. coli* O157:H7 in Walkerton, Canada

Cryptosporidiosis in Milwaukee, March/April 1993

- 403,000 estimated cases; > 50 deaths
  - predominantly in southern Milwaukee (nursing home residents survey)
- Southern Milwaukee plant (March-April 1993)
  - streaming-current monitor not properly installed
  - coagulation sub-optimal
  - negative for coliforms
  - turbidity peaked in late-March/early April
  - plant closed on April 8
- Source: cow manure run-offs, human sewage

Canadian outbreak of waterborne *E. coli* O157:H7 (Walkerton, Ontario) in May 2000

An aerial view of Well #5 and the surrounding area.

- Heavy rains
- Manure runoff
- Contaminated municipal well
- Not enough chlorine
- Reporting?
- 7 deaths, several thousands infected
- Boil advisory for 6 months

Can an outbreak of (waterborne) gastroenteritis be easily detected? (Payment 1995)

Population 1,000,000
MD 2,000
Hospitals 10

	Outbreak (1 month)		Endemic level
	Norwalk	Crypto	1/person/yr
Infection rate (% population)	**50%**	**25%**	**-**
Symptomatic (=x% infected)	**10%**	**25%**	**100%**
Acute (=x% symptomatic)	**1%**	**1%**	**1%**
Hospitalized (=x% acute)	**1%**	**1%**	**1%**
# Infected/week	**500,000**	**250,000**	**-**
# Symptomatic/week	**50,000**	**62,500**	**19,231**
# Acute (Visits MD)/week	**500**	**625**	**192**
# Hospitalized/week	**5**	**6**	**2**
# seen by MD/week	**0.3**	**0.3**	**0.1**
# per hospital/week	**0.5**	**0.6**	**0.2**

Waterborne diseases prevention - Conclusions

- Watershed management
- Water treatment → multiple barriers
  - coagulation/flocculation
  - filtration
  - disinfection
- Better disinfectants/residuals
  - disinfectant by-product issues
- Cost vs. risk